Meetings and Conferences

SYMPOSIUM ON PHYSICAL FUNDAMENTALS OF THE ELECTROPHOTOGRAPHIC PROCESS

V. M. FRIDKIN

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ELECTROPHOTOGRAPHY is one of the new and most promising developments of technical physics. Although the first work on electrophotography was carried out in the USA in the late thirties, several new developments occurred in the Soviet Union during the last five years, so that extensive experimental material of practical importance has by now been accumulated. Research in electrophotography is now being carried out in many research establishments of the Academies and their branches. Among these are a specialized institute in Vilnius dealing with problems of electrophotography, the Crystallography Institute of the U.S.S.R. Academy of Sciences, the Laboratory for Aeromethods of the U.S.S.R. Academy of Sciences, the S. I. Vavilov State Optical Institute, and many other scientific establishments.

The electrophotographic process in greatest use at present is the one based on surface charging of photoconducting polycrystalline layers (xerography). High-resistance photoconducting layers ($\rho \geq 10^{12}$ ohm-cm) made of amorphous selenium, zinc oxide, cadmium sulfide, and several other phosphors are used for this purpose. Photoconductors of relatively low resistivity, such as zinc oxide and cadmium sulfide, are first dispersed with a highly insulating binder, after which they are deposited on a corresponding backing. For example, electrophotographic layers of zinc oxide, deposited directly on paper and thus analogous to ordinary silver-bromide papers, are extensively used. The electrophotographic layers are usually surface-charged by corona discharge in air, although this can also be done by surface electrification. When the charged layer is exposed, its external field is reduced by the photoconductivity. This can be caused either by direct recombination of the carriers, or by formation of electric double layers. Thus, if an image is projected on the surface of a charged (sensitized) electrophotographic layer, a potential relief is produced and forms the latent image. This latent image can be developed by electrophotographic developers, which comprise an aggregate of dielectric particles that carry a charge of opposite polarity. In some cases the triboelectric effect is used for these purposes (dry developers), while in others the electrophoresis phenomenon is used (liquid developers). The optical sensitization of the internal photoeffect in zinc oxide by means of organic dyes, discovered by E. K. Putseĭko and A. N. Terenin [Doklady AN SSSR **70**, 401 (1950)], has laid the groundwork for research in sensitization of electrophotographic layers and the development on this basis of layers with specified spectral sensitivity.

A recently discovered and thoroughly investigated phenomenon is electrophotography on photoelectrets.* The photoelectret state, which accompanies photoconductivity in crystals, consists in the crystal acquiring by illumination in the applied field a stable internal polarization, which is retained in the crystal for a long time after the removal of the external field and cessation of the illumination. The illumination of the photoelectret brings about its depolarization. The photoelectret state is observed in sulfur, cynnabar, anthracene, and many other crystals and polycrystalline dielectrics. Photoelectret electrophotographic layers can acquire a latent image either by polarization (negative image) or through depolarization by illumination (positive). In the case of photoelectrets, the darkness regression of the latent image is relatively slow. The image in photoelectret layers can be developed in the same fashion as indicated above. Let us add that recently various workers have described many new versions of the electrophotographic process, based on polarization of dielectrics.

Even the foregoing very brief review shows that the electrophotographic process is not an isolated physical occurrence, but is based on the use of an entire set of physical phenomena, which hitherto have not been considered together or in any connection with each other. It is sufficient to point out that the latent electrophotographic image is the result of a complicated set of electronic, ionic, and relaxation processes in crystals, while the development is based on a no less complicated set of phenomena such as static electrification, which have not been systematically investigated apart from rare exceptions.†

This circumstance explains the interest aroused by the Symposium on Physical Fundamentals of the Electrophotographic Process, organized by the Institute of Crystallography of the U.S.S.R. Academy of Sciences (November 24-26, 1960). About one hundred representatives of more than fifteen scientific organizations participated in this symposium, where twenty-two papers were delivered at five sessions.

The papers of the first session were devoted to investigations of the electret state of dielectrics and to

*V. M. Fridkin and I. S. Zheludev Фотоэлектреты и электрофотографический процесс (Photoelectrets and the Electrophotographic Process), Moscow, Academy of Sciences Press, 1960.

†L. B. Loeb, Static Electrification, Berlin, Springer 1958.

the use of electrets in electrophotography. An interesting paper by A. N. **Gubkin** (Physics Institute, Academy of Sciences) "Residual Polarization in Polycrystalline Titanates of Alkali-Earth Metals and its Role in the Electret Effect" summarized the results of researches on residual polarization in thermal electrets made of titanates of alkali-earth metals. It follows from the data quoted in the paper that the residual polarization in the investigated thermoelectrets is on the order of 10^{-4} Coulomb/cm^2, which indeed brings about the electret effect. This residual polarization increases rapidly with temperature and with the polarization time of the corresponding dielectrics, but remains practically unchanged when the electrets are stored at room temperature (for one year). At higher temperatures, this polarization decreases exponentially with time (the corresponding activation energy is $U = 0.6$ ev). The paper by A. N. Gubkin gave rise to lively discussion, particularly in connection with the problem of the general nature of the mechanisms causing the thermoelectret and ferroelectric states of dielectrics.

The paper by V. M. **Fridkin** (Institute of Crystallography, Academy of Sciences U.S.S.R.) reported research on the glow of electretized zinc-sulfide layers under the influence of a constant electric field of direction opposite to that of the polarization field. Data on the first observations of this effect were published by the author earlier. [Doklady AN SSSR **131**, 290 (1960), Soviet Phys.-Doklady **5**, 301 (1960).] The present paper reports the observation of a unique extinction effect, wherein excitation of an electretized layer with red light has led to a change in the minimum value of the intensity of the constant electric field (called critical) at which glow is observed. With increasing wavelength, the critical intensity of the reverse field decreased. The results obtained have enabled the author to suggest that a tunnel excitation mechanism is responsible for the observed luminescence. This extinction effect was used as the basis of a new version of electrophotographic process, reported in the paper by **I. S. Zheludev**, **Yu. N. Barulin**, and **V. M. Fridkin** (Institute of Crystallography, U.S.S.R. Academy of Sciences, and NIIPoligrafmash [Scientific Research Institute for Polygraphic Machinery]). The authors charged a ZnS-Cu layer by corona discharge, after which they projected an image on the charged layer through a red filter. With a reverse field of less than critical intensity applied to the exposed layer, the authors observed luminescence of the latent image, due in this case not to the distribution of the charges or of the field, but to unequal extinction conditions in different portions of the layer. Thus, at room temperature, a photograph was obtained in the wavelength region down to $1.1\,\mu$. At low temperature, the red boundary of this effect can be shifted toward the longer wavelengths.

Great interest and lively discussion was aroused by the paper of E. I. **Adirovich** (Physics Institute, Academy of Sciences) "Distribution of Heterocharge and of Field in Photoelectrets." The author presented a solution of the problem of the stationary distribution of the space-charge density and of the field intensity in a single-crystal photoelectret. In the case of low donor excitation and low acceptor filling (which is the prevalent situation), the solution of the problem can be expressed in terms of the Weierstrass elliptic function. In this case the space-charge density distribution is antisymmetrical with respect to the center of the crystal. It was shown that the space charge is concentrated in sufficiently narrow layers of the crystal near the electrodes, and that the layer thickness is independent of the intensity of the polarizing field.

An interesting communication by I. **Ya. Lyamchev** and I. N. **Orlov** summarized the results of an investigation of stable polarization in electroluminescent layers, and principally of its effect on the pecularities of the electroluminescence of these layers under the influence of electric pulses.

Another group of papers was devoted to optical sensitization of electrophotographic layers by organic dyes and to several problems connected with the nature of this phenomenon. The paper by N. N. **Markevich** and E. K. **Putseĭko** (NIIÉlektrografii [Scientific Research Institute for Electrophotography] and State Optical Institute) was devoted to a study of the adsorption isotherm of fluorescein and erythrosine and its influence on the photo-emf of sensitized zinc oxide. By using the condenser method, the authors have established that the maximum of photosensitivity for sensitized zinc oxide takes place when 70% of the monomolecular layer is filled with dye. In this concentration region, the corresponding isotherms obey the Langmuir equation. The results obtained can be used directly to improve the procedures for optical sensitization of electrophotographic layers.

Great interest was aroused by the paper by I. A. **Akimov** (State Optical Institute) "On the Inertia of the Process of Optical Sensitization," in which the author made an attempt, based on a whole set of researches, to determine the time necessary to transfer energy or an electron from the sensitizing dye to the semiconductor. It is concluded in this paper that this time does not exceed 10^{-9} sec. This result is quite promising, since it indicates that the sensitivity of the corresponding electrophotographic layer is limited not by the inertia of the optical sensitization process, but by the kinetics of the electronic process in the semiconductor lattice.

In a communication by **F. I. Levina** and **I. Z. Plavina** (NIIÉlektrografii) "Spectral Characteristics of Sensitized Photosemiconductor Layers" the authors treated the spectral distribution of photocurrent in zinc oxide sensitized with fluorescein, eosin, tripaflavine and pinacyanol. The authors call attention to the shifts of the curve of spectral distribution of the photocurrent of the sensitized layer toward the short-wave region, compared with the curve of spectral absorption of the corresponding solutions of the dyes. It is suggested in the paper that this shift is due to the joint action of the oxygen ions and the dye molecules adsorbed on the zinc oxide. According to the authors, combined sensitization of zinc oxide with two dyes is equivalent to the intensification of the action of the dye whose maximal absorption is at the shorter wavelength.

In a paper by **B. Vasilyauskaite**, **Yu. Vishchakas**, **Yu. Zibuts**, **M. Parkhomenko**, and **T. Yanauskas** (NIIÉlektrografii) "Relaxation of Photoconductivity of Electrophotographic Layers of Zinc Oxide Sensitized with Eosin" data are given on stationary photoconductivity, relaxation time, and lux-ampere characteristics of the transverse and longitudinal photo effects in zinc oxide sensitized with eosin. The results obtained are interpreted by the authors on the basis of the theory of A. Rose [RCA Review **12**, 362 (1951)]. In a paper by **N. M. Melankholin**, and also in a paper by **E. N. Slavnova** (Institute of Crystallography, Academy of Sciences), interesting data were given on semiconductor properties of dye crystals and methods of introducing dyes into growing crystals.

At another session of the symposium, papers were delivered on certain general properties of electrophotographic layers. Great attention was paid to the paper by **S. G. Grenishin** and **Yu. A. Cherkasov** (State Optical Institute) "Electric and Photoelectric Properties of Selenium-Telluride Electrophotographic Layers." The authors investigated, by the dynamic-electrometer method, the spectral sensitivity of the aforementioned layers on different backings, at different layer heat treatment, and charging conditions. Of considerable interest to the participants of the symposium was the paper by **S. A. Semiletov** (Institute of Crystallography, Academy of Sciences), in which data were given on the structure of thin selenium layers. The paper by **Yu. K. Vishchakas**, **V. I. Gaĭdelis**, **E. A. Montrimas**, and **E. M. Suveĭzdis** (NIIÉlektrografii) was devoted to an investigation of the influence of metal oxides, introduced into the electrophotographic layer in the form of impurities, on the charging potential and on the dark potential drop of the corresponding layer. The paper by **É. I. Adirovich** and **V. M. Fridkin** (Physics Institute, Academy of Sciences and Institute of Crystallography, Academy of Sciences) was devoted to the analysis of the validity of the reciprocity law in electrophotography and to the connection between reciprocity and conditions of quasi-stationary excitation of the crystal.

Two sessions of the symposium were devoted to the mechanism and kinetics of development of the latent electrophotographic image, and also to problems of sensitometry and sensitivity of the electrophotographic process. Great interest was aroused by the paper by **I. I. Zhilevich** (NIIÉlektrografii) "On the Role of the External Field of the Latent Electrophotographic Image," which contained the results of research on the kinetics of development based on the equivalent-circuit method. The author believes that complete development of the latent image is due to the formation of a double electric layer, and only partial recombination of charges of the developer and the electrophotographic layer. The paper by **I. V. Anfilov** (NIIPoligrafmash) was devoted to a theoretical and experimental study of the kinetics of the development of the latent image with the aid of liquid developer. The paper by **S. I. Khotyanovich** (NIIÉlektrografii) contained an interesting analysis, of practical importance, of the causes of distortion in the development of electrophotographic layers. In a joint paper by **S. I. Khotyanovich** and **A. Yu. Gikene** (NIIÉlektrografii) the influence of the composition of liquid developers on their properties was discussed. In a paper "Certain Problems in the Development of Electrographic Layers" by **K. M. Vinogradov** (State Optical Institute), much attention was paid to the analysis of the edge effect and to the use of the method of counter electrode during the development. **Yu. E. Karpeshko** (NIITS) in his paper gave a comparative estimate of factors influencing the sensitivity of the electrophotographic process, and gave some data on the use of electrophotography for copying images from the screen of a cathode ray tube. A lively discussion was aroused by the paper by **A. B. Dravin** (VNIIPPiT [All-Union Research Inst. of Polygraphic Industry and Technology]), devoted to questions of sensitometry and improvement in the procedures for the exposure of electrophotographic layers. The participants heard with great interest a paper by **E. S. Borisevich**, **I. I. Zhilevich**, **L. E. Aronov**, **S. V. Arshvil**, **M. V. Zabelin**, and **M. S. Mosyagin** (Institute of Earth Physics, Academy of Sciences, and NIIÉlektrografii) on a seismic oscillograph, in which the signals are recorded on an electrophotographic layer.

The results of the symposium indicate that further research must be carried out to study the mechanism of formation of the latent electrophotographic image, and in particular the electrostatics of the latent image and the mechanisms and kinetics of its development. Only in this way can the nature of the sensitivity of the electrophotographic layers be understood and the factors that limit its value determined. At the same time, the results of this symposium demonstrate the promise offered by the development of principally new electrophotographic methods, based on electronic processes in crystals.

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